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Report Title

Final Report: Time-frequency computational model for echo-delay resolution in sonar images of the big brown bat, eptesicus fuscus

ABSTRACT

Biosonar animals have a remarkably accurate and noise tolerant sonar. Some bats use their auditory system to achieve full 3D navigation capabilities and prey discrimination. They reach a resolution in the sub-millimeter range. Likewise, some dolphins utilize their auditory system to achieve a combination of 3D navigation and internal object examination that far exceeds the abilities of our current ultrasound and underwater sonar technology. We have devoted our research efforts during the last year of the project into utilizing the knowledge about biosonar that we have gained at previous years to developing practical sonar techniques for the benefit of homeland security tasks as well as medical applications. Specifically, we demonstrate improved underwater sonar resolution and ultrasound imagery.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

1. M. I. Sanderson, N. Neretti, N. Intrator and J. A. Simmons. Evaluation of an auditory model for echo delay accuracy in wideband biosonar. Journal of the Acoustical Society of America 114(3), pp. 1648-59, September 2003.

2. J. A. Simmons, N. Neretti, N. Intrator, Richard Altes, Michael J. Ferragamo and M. I. Sanderson. Delay accuracy in bat sonar is related to the reciprocal of normalized echo bandwidth, or Q . Proceedings, National Academy of Science (PNAS) 101(10) pp. 3638-3643, March 9, 2004.

3. N. Neretti, N. Intrator and L. N Cooper. Adaptive pulse optimization for improved sonar range accuracy. IEEE Signal Processing Letters 11(4), pp. 409-412, April 2004.

4. K. Kim, N. Neretti and N. Intrator. Mosaicing of Noisy Acoustic Camera Images. IEE Proc. Radar, Sonar & Navigation In press.

5. L. Yu, N. Neretti and N. Intrator. Multiple ping sonar accuracy improvement using robust motion estimation and ping fusion. J. Acoust. Soc. America. In press.

Number of Papers published in peer-reviewed journals: 5.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Papers presented at meetings, but not published in conference proceedings (N/A for none)

1. K. Kim, N. Neretti and N. Intrator Image registration and mosaicing of acoustic camera images. VIIP 2004 Spain, September, 2004.

2. N. Neretti, N. Intrator and L. N Cooper Pulse-Train Based Time-Delay Estimation Improves Resiliency To Noise. IEEE International Workshop on Machine Learning for Signal Processing pp. 213-222, Brazil, Sep. 2004.

3. K. Kim, N. Neretti and N. Intrator Acoustic Camera Image Mosaicing and Super-resolution . Ocean 2004 Kobe Japan, November, 2004.

4. N. Intrator, N. Neretti and Q. Huynh Sonar object discrimination via spectral density. Ocean 2004 Kobe Japan, November, 2004.

5. N. Neretti, L. N Cooper and N. Intrator Improved Noise Tolerance for Sonar Applications in Critical Environments. CIHSPS05. Apr 1, 2005.

6. K. Kim, N. Neretti, and N. Intrator Construction of High Resolution Image from Multiple Frames of Acoustic Camera Images. CIHSPS05. Apr 1, 2005.

7. L. Yu, N. Neretti, and N. Intrator Robust Motion Estimation Improves Underwater Sonar Accuracy. CIHSPS05. Apr 1, 2005 .

Number of Papers not Published: 7.00

(d) Manuscripts

Number of Manuscripts: 0.00

Number of Inventions:

Graduate Students

Ki-O Kim

Number of Graduate Students supported: 1.00

Total number of FTE graduate students: 1.00

Names of Post Doctorates

Nicola Neretti

Number of Post Docs supported: 1.00

Total number of FTE Post Doctorates: 0.00

List of faculty supported by the grant that are National Academy Members

Leon N Cooper

Names of Faculty Supported

Leon N Cooper
Nathan Intrator

Number of Faculty: 2.00

Names of Under Graduate students supported

Number of under graduate students: 0.00

Names of Personnel receiving masters degrees

Number of Masters Awarded: 0.00

Names of personnel receiving PHDs

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Names of other research staff

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Inventions (DD882)

5 **Apparatus and method for performing time delay estimation of signals propagating through an environment**

Patent Filed in US? (5d-1) Y

Patent Filed in Foreign Countries? (5d-2) N

Was the assignment forwarded to the contracting officer? (5e) Y

Foreign Countries of application (5g-2):

5a: Nathan Intrator

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5 **Estimation of background noise and its effect on sonar range estimation**

Patent Filed in US? (5d-1) Y

Patent Filed in Foreign Countries? (5d-2) N

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5a: Nicola Neretti

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5 **Noise adaptive sonar signal processor**

Patent Filed in US? (5d-1) Y

Patent Filed in Foreign Countries? (5d-2) N

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Final Progress Report
September, 2004

Grant ARO DAAD 19-02-1-0403

Program Officer: Dr. Elmar T. Schmeisser

Nathan Intrator, Leon N Cooper
Institute for Brain and Neural Systems
Brown University

Keyword Echo Delay Estimation, Multiple Sonar Pings, Image Mosaic, Acoustic Camera, Motion Estimation

Abstract

Biosonar animals have a remarkably accurate and noise tolerant sonar. Some bats use their auditory system to achieve full 3D navigation capabilities and prey discrimination. They reach a resolution in the sub-millimeter range. Likewise, some dolphins utilize their auditory system to achieve a combination of 3D navigation and internal object examination that far exceeds the abilities of our current ultrasound and underwater sonar technology. We have devoted our research efforts during the last year of the project into utilizing the knowledge about biosonar that we have gained at previous years to developing practical sonar techniques for the benefit of homeland security tasks as well as medical applications. Specifically, we demonstrate improved underwater sonar resolution and ultrasound imagery.

Specific accomplishments

We have demonstrated increase in sonar resolution and accuracy as well as resiliency to noise utilizing our previously developed multiple ping sonar (MPS) and our newly developed motion estimation technique. This was demonstrated theoretically using the Woodward graph of resolution vs. SNR and practically using simulations run on the Field II Sonar simulator. Technical details are provided in (Yu et al., 2005).
We have demonstrated improved image quality, resolution, reduced background noise, and increase in field of viewing on real-world sequences of the Forward Looking, Dual Frequency Identification Sonar (DIDSON). Technical details and results appear in (Kim et al, 2005).

Results

Below, we provide some technical details of the results that we have achieved utilizing our proposed biosonar inspired approach to sonar imagery. First, we demonstrate an empirical graph obtained using a simulation of an underwater sonar simulation. The figure demonstrates the level of improvement in sonar accuracy

And break point shift from 16dB to 9dB can be observed in panel D representing a significant improvement in sonar range. Also, an accuracy improvement of an order of

magnitude can be observed in panel D, which is very close to the theoretical improvement limit that can be seen in Panel A.

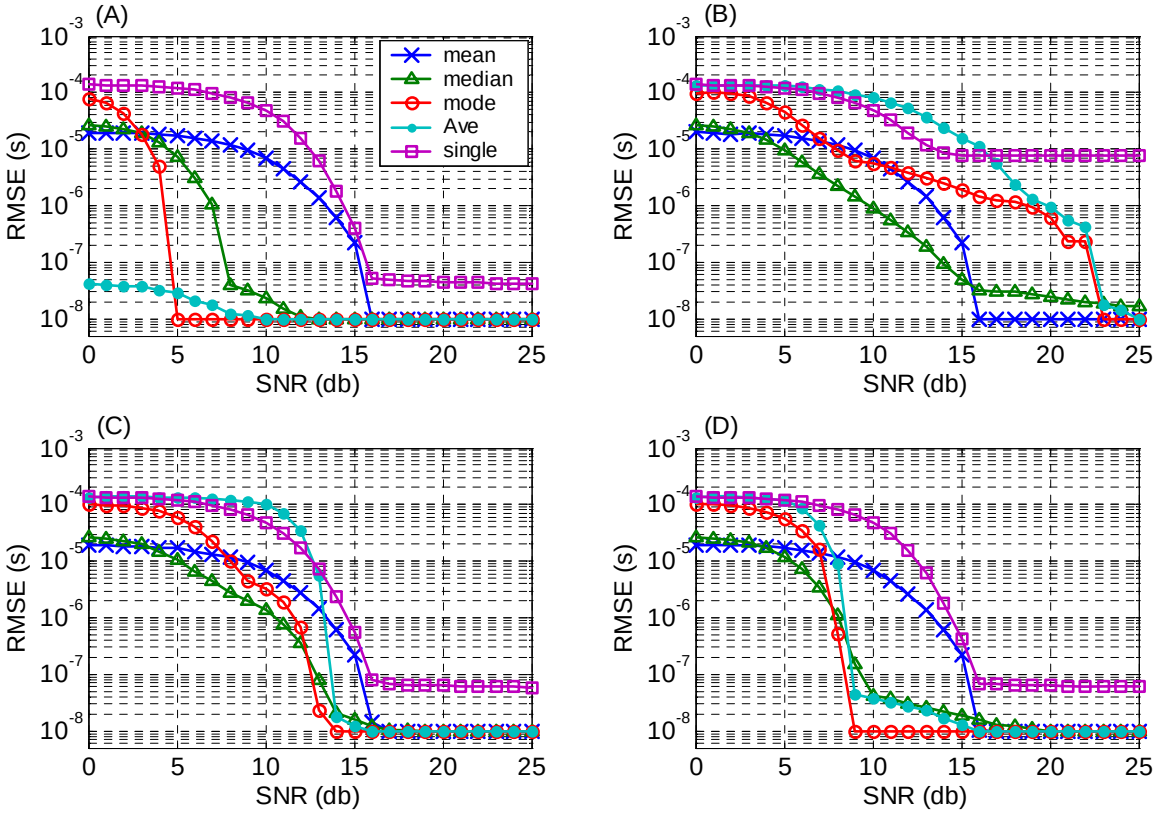

Fig.1 Demonstration of improved sonar accuracy and shift in break point. Panel A demonstrates sonar accuracy as a function of SNR for several methods of locating sonar echo returns. Full details appear in (Yu et al, 2005). As was demonstrated in (Neretti et al, 2004), the mode function (orange line) provides best estimate and its breakpoint is at 5dB. Panel A depicts results of fusion of 50 pings with no motion between the target and sonar. Panel B depicts the same fusion result when there is motion but no motion correction. Panel C demonstrate conventional motion correction and panel D demonstrates results of our best motion correction algorithm. Due to this motion correction, sonar accuracy at a level of no motion is achieved (an order of magnitude improvement over single ping sonar), and sonar breakpoint shifts from 16dB to 8dB indicating a significant range increase.

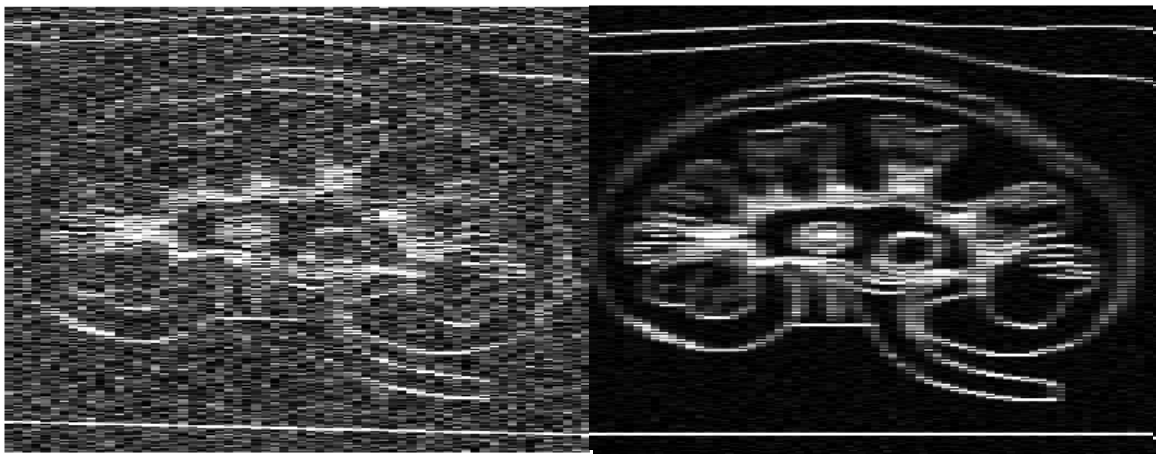

Fig. 2 Demonstration of the effect of ultrasound image reconstruction from multiple ultrasound pings. The panel on the left depicts a phantom of a kidney that is obtained using the Filed II ultrasound simulator at 10dB SNR. The panel on the right demonstrates a significantly improved image which is obtained using our MPS technique (Neretti et al. 2004).

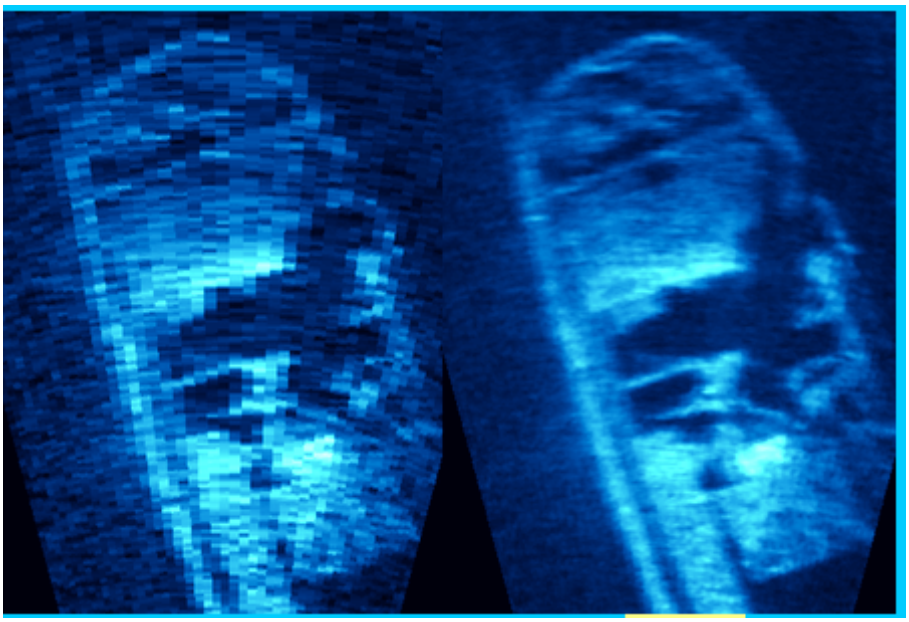

Fig. 3. Demonstration of improved forward-looking sonar image quality using our multiple view technique. On the left is an image obtained by the DIDSON and on the right is the same image after being fused from multiple views. A clear improvement in pixel resolution, clarity and background noise reduction can be seen.

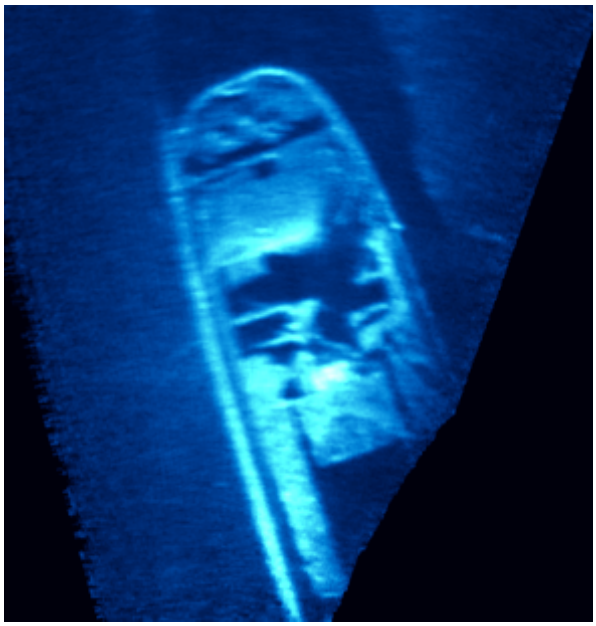

Fig. 4. Demonstration of increase in field of view that can be achieved by effectively fusion the sonar imagery from multiple views. The image has been created from a collection of images similar to the image on the left in Fig 3. As can be clearly seen, the fusion leads to a significant improvement in image quality and clarity with sharper image details. Such clarity which has not been obtained by other forward looking sonar systems, demonstrate that a forward looking sonar may be a powerful device in protecting ports, underwater military and civilian installation as well as military and civilian vessels against terrorist attacks and natural disasters.

Impact

We have introduced a novel and very promising approach to fusion information from multiple observations and have demonstrated its usefulness in underwater sonar systems and medical ultrasound. We believe that improving sonar accuracy has a tremendous impact on being able to see better underwater. It immediate use is the safeguard of sensitive underwater areas such as nuclear sub marine bases as well as guarding oil rigs in the ocean, an issue that has become very important following the latest wave of hurricanes.

The impact on medical ultrasound is also immense, as improved resolution (with lower energy) can reduce potential harm to fetus and improve detection and thus early intervention in various medical problems such as colon cancer, kidney problems etc.

It is important to note that while there has been great improvement in various image assessment tools such as CT and MRI, Ultrasound is still the only non-harmful and non invasive tool and thus, improvement in its accuracy, can lead to a diagnostic tool that has the image resolution of a CT but at a fraction of the cost and no harmful radiation effect.

Publications

Journal Papers

1. **M. I. Sanderson, N. Neretti, N. Intrator and J. A. Simmons.** Evaluation of an auditory model for echo delay accuracy in wideband biosonar. *Journal of the Acoustical Society of America* 114(3), pp. 1648-59, September 2003.

2. **J. A. Simmons, N. Neretti, N. Intrator, Richard Altes, Michael J. Ferragamo and M. I. Sanderson.** Delay accuracy in bat sonar is related to the reciprocal of normalized echo bandwidth, or Q . *Proceedings, National Academy of Science (PNAS) 101(10) pp. 3638-3643, March 9, 2004*
3. **N. Neretti, N. Intrator and L. N Cooper.** Adaptive pulse optimization for improved sonar range accuracy. *IEEE Signal Processing Letters* 11(4), pp. 409-412, April 2004.
4. **K. Kim, N. Neretti and N. Intrator.** Mosaicing of Noisy Acoustic Camera Images. *IEE Proc. Radar, Sonar & Navigation* In press.
5. **L. Yu, N. Neretti and N. Intrator**. Multiple ping sonar accuracy improvement using robust motion estimation and ping fusion. *J. Acoust. Soc. America.* In press.

Conference Papers

1. **K. Kim, N. Neretti and N. Intrator** Image registration and mosaicing of acoustic camera images. *VIIP 2004* Spain, September, 2004
2. **N. Neretti, N. Intrator and L. N Cooper** Pulse-Train Based Time-Delay Estimation Improves Resiliency To Noise. *IEEE International Workshop on Machine Learning for Signal Processing* pp. 213-222, Brazil, Sep. 2004.
3. **K. Kim, N. Neretti and N. Intrator** Acoustic Camera Image Mosaicing and Super-resolution . *Ocean 2004* Kobe Japan, November, 2004
4. **N. Intrator, N. Neretti and Q. Huynh** Sonar object discrimination via spectral density. *Ocean 2004* Kobe Japan, November, 2004
5. **N. Neretti, L. N Cooper and N. Intrator** Improved Noise Tolerance for Sonar Applications in Critical Environments. *CIHSPS05.* Apr 1, 2005
6. **K. Kim, N. Neretti, and N. Intrator** Construction of High Resolution Image from Multiple Frames of Acoustic Camera Images. *CIHSPS05.* Apr 1, 2005
7. **L. Yu, N. Neretti, and N. Intrator** Robust Motion Estimation Improves Underwater Sonar Accuracy. *CIHSPS05.* Apr 1, 2005

Books

8. **Leon N Cooper, N. Intrator, Brian S. Blais and Harel Z. Shouval** Theory of Cortical Plasticity. World Scientific, 2004

Patent applications

1. **N. Intrator, L. N Cooper and N. Neretti**, "Noise adaptive sonar signal processor", PCT/US2004/018059, 08 June 2004.
2. **N. Intrator, L. N Cooper and N. Neretti**, "Estimation of background noise and its effect on sonar range estimation", PCT/US2004/018219, 08 June 2004.
3. **N. Intrator and K. Kim, N. Neretti and L. N Cooper**, "Apparatus and method for performing time delay estimation of signals propagating through an environment", PCT/US2004/025373, 05 August 2004.